Endogenous technology sharing in R&D intensive industries

Derek J. Clark and Jan Yngve Sand

Working Paper Series in Economics and Management
No. 06/06, June 2006

Department of Economics and Management
Norwegian College of Fishery Science
University of Tromsø
Norway

Endogenous technology sharing in R&D intensive industries*

Derek J. Clark and Jan Yngve Sand†

Department of Economics,

University of Tromso, Norway

June 26, 2006

Abstract

This paper analyses the endogenous formation of technology sharing coalitions with asymmetric firms. Coalition partners enjoy perfect spillovers from technology advancements by their coalition partners, but each firm determines its R&D investment level non-cooperatively and there is no co-operation in the product market. We show that the equilibrium coalition outcome is one between the two most efficient firms, and that this is also the preferred outcome of a welfare maxmising authority. Furthermore, we show that the equilibrium outcome results in the lowest total R&D investment of all possible outcomes.

JEL Classification: L11, L13

Keywords: R&D, endogenous coalitions, asymmetric firms

*We would like to thank seminar participants at the University of Tromso and the University of York for valuable comments, and in particular Bipasa Datta, Luigi Siciliani and Øystein Foros. This paper is part of the project "The knowledge-based society" sponsored by the Research Council of Norway (Project 172603/V10).

†Corresponding author: Department of Economics, NFH, University of Tromso, NO-9037 Tromso, Norway. Tel. + 4777645540, e-mail: jan.sand@nfh.uit.no.

1 Introduction

In this paper we are interested in analyzing the endogenous formation of technology sharing partnerships, or coalitions, in industries with a limited number of firms. In terms of the treatment in competition policy cases, R&D mergers or Research Joint Ventures (RJVs) are treated as exception from the prohibition of cooperation (e.g., Article 81 in EU Treaty of Rome, which deals with agreements among firms). The primary reason for this is that there is a public good aspect to R&D which may make it difficult to achieve socially optimal levels of R&D activity if focusing exclusively on non-cooperative R&D. RJVs can take various forms, ranging from simple information sharing arrangements with non-cooperative investment decisions by separate R&D units, to fully integrated R&D units where investment decisions are made to maximize joint profits.

An important aspect of public policy with respect to R&D in many countries is the focus on how to increase R&D levels to the OECD average.[1] Although this is a useful starting point, the total level of R&D is not necessarily the most appropriate measure of success as the characteristics of the R&D intensive industries also matter. The present analysis is exclusively focused on firms' privately financed R&D investments, and we do not look at R&D undertaken and financed by public funds. Consequently, the R&D levels we observe in the context of the present model is only half the picture. As we show below, the equilibrium coalition outcome is the least desirable outcome if the main objective is to increase R&D investments. This would imply that if competition policy authorities allow such a coalition to go through, the public sector will need to finance an even larger share of the total R&D investments to achieve a higher level of investments. This may quite possibly be seen as good news for universities and research institutes.

There are three firms in our model that all have different *ex ante* levels of marginal cost in producing the final product. The firms undertake R&D investments which we model as a type of process innovation, where the investments reduce the marginal cost (of producing the final product) for both the investing firms and that of its coalition partners.[2] The type of R&D undertaken should be thought of in terms of implementation of new technology rather than the discovery of new processes, since there is no uncertainty with respect to the outcome of the R&D investment. The three firms compete in quantities in the product market, and we assume that there is no cooperation other than the potential to share technological advancements among coalition partners.[3] We consider a simple type of R&D cooperation, and focus on coalition formation with

[1] The Norwegian government has discussed this in a White Paper: St. Prp 51 (2002-2003) Virkemidler for et innovativt og nyskapende næringsliv (Innovasjonsmeldingen).

[2] Some stylised facts on what is termed "informal knowhow sharing" in various industries can be found in von Hippel (1987). Carter (1989) investigates the economic incentives behind sharing of technical information.

[3] For the analysis of the sharing of private cost and demand information in oligopolies, see for instance Fried (1984), Gal-Or (1985, 1986), Shapiro (1986), Vives (1984), and Okuno-Fujiwara, Postlewaite and Suzumura (1990). Whereas these papers consider the exchange of information in asymmetric information models which affects the firms' perception of the competition, the present analysis is concerned with exchange of information that directly affects the marginal cost of production of the partners to a coalition. The link is, as pointed out by Eaton and

technology sharing in a static game. By this we mean that coalition partners benefit fully from any technological advancements that their partner undertakes, but the investment decisions are taken non-cooperatively. There is no benefit for the firm outside the arrangement of the R&D undertaken by the coalition partners. Thus, there is perfect spillover within the coalition and zero spillover to the outsider. Eaton and Eswaran (1997) show in the context of a supergame that trading of technical information can be sustained as an equilibrium. The mechanism to sustain sharing is through punishments (ejection from the coalition if providing empty information). The trading of technical information may reduce the marginal cost of production for the partners of a coalition in a similar way to the present analysis, but in Eaton and Eswaran (1997) firms have *ex ante* identical marginal cost of production, which implies that all firms in a coalition have identical marginal cost when all relevant information is traded in the coalition.

This set-up could also be interpreted as one in which patent holders enter into a patent pool, with each member of the pool being allowed to (costlessly) utilize cost reducing technology advancements made by their partners.[4] The endogenous formation of the coalition, or pool, will then determine the scope of the pool (i.e., how many, if any, pool partners will there be). There is also some resemblance to the literature on open source, which by some authors is termed collective invention.[5] The idea behind the sharing of technology advancements in the present analysis also bears some resemblance to the theory of club goods, where the members of the club can benefit from all the facilities of the club.[6]

We are ruling out the possibility of a monopoly coalition, and focus only on the potential outcomes of either some coalition with two firms or the case with no coalition. In addition, we attempt to rank the various outcomes in terms of impact on industry profit, consumers' surplus and ultimately on welfare. Although our primary focus is not on mergers, we make use of the methodology developed by Horn and Persson (2001) to characterize the equilibrium coalition structure and to investigate the impact on R&D investment levels of the potential outcomes.[7]

The equilibrium coalition is a result of a cooperative bargaining process in which firms can communicate freely with each other and are free to write binding contracts with each other (Horn and Persson, 2001).[8] One main feature of this approach is that the lack of restrictions on the

Eswaran (1997), that the information that is exchanged is both cases non-rivalrous.

[4] For analysis of the welfare effects of patent pools in a different setting see Lerner and Tirole (2004).

[5] On open source see, e.g., Lerner and Tirole (2005). The term collective invention is often attributed to Allen (1983) and describes "the free exchange of information about new techniques and plant designs among firms in an industry".

[6] Buchanan (1965) is the seminal article on the theory of club goods.

[7] Barros (1998) also considers endogenous mergers with a similar set of criteria to determine the equilibrium market structure. Vasconcelos (2006) considers endogeous mergers in endogenous sunk cost industries to derive upper bounds on concentration.

[8] Horn and Persson (2001) cites various work on endogenous mergers, and note that there seems to be three different paths to analysing endogenous mergers. They give an account of the pros and cons of the different approaches: i) Model the process as a normal form game with bids and asking prices (Kamien and Zang, 1990,

contracts between coalition partners implies that the free-riding problem becomes less pronounced, and one would expect that the solutions with respect to the equilibrium market structure becomes more efficient. We show that the equilibrium coalition is a coalition between the two most efficient firms. It is not necessarily obvious that the two most efficient (and hence) largest firms would choose to share their technology advancements. Our model predicts a result along the line of "keep your friends close, but your enemies closer". One might initially be tempted to deduce that the more efficient firm would prefer to go into partnership with the least efficient firm, or that the two least efficient firms would join forces to be able to outcompete the *ex ante* most efficient firm. This, however, turns out not to be the case here. In addition, the analysis of mergers often reveals conflicting interests between social and private merger incentives. This is, in particular, due to the fact that the mergers that are chosen endogenously are mergers that result in high industry profit, which is often deemed to be incompatible with high consumers' surplus. In the present analysis, however, the endogenously chosen coalition is also the coalition that maximizes welfare and the coalition that achieves the highest industry profit is also the coalition that results in the highest total output.

The rest of the paper is organized as follows: In section 2 we present the basic model and the non-coalition outcome. In section 3, 4 and 5 we analyze the three possible coalition structures. In section 6 we compare the R&D investment levels under the different technology sharing coalitions, and in section 7 we endogenize the coalition formation. In section 8 we look at welfare aspects of the different coalitions, and in section 9 we make some concluding remarks.

2 The benchmark model

There are three firms indexed by i, j and k who produce a homogenous product for which the inverse demand function is

$$p = 1 - (q_i + q_j + q_k) \tag{1}$$

where p is the product price, and q_a is the quantity produced by firm a. The initial marginal production cost faced by each firm is $c_a = \theta_a c$ for $a =, i, j, k$, and where $c > 0$ and $\theta_k > \theta_j > \theta_i$. At stage 1, each firm has the possibility of investing in R&D in order to reduce this marginal cost; the cost of R&D is the same for each firm: $k(x_a) = \frac{\gamma x_a^2}{2}$, where x_a is the amount of R&D undertaken by firm a. Marginal cost is affected by R&D in the following way:

$$\widehat{c}_a = \theta_a c - x_a \tag{2}$$

1991), ii) Merger formation as a non-cooperative bargaining process (Chatterjee et al, 1993, and Ray and Vohra, 1999), and iii) Merger formation as a cooperative game (Horn and Persson, 2001). The present paper follows the third approach.

where $\widehat{c}_a$ is post R&D cost for firm a. We assume initially that there are no spillovers from one firm's investment to the others. At stage 2 the firms compete in quantities in the product market. In contrast to the majority of the literature on strategic R&D investments where there typically are imperfect spillovers between investing firms, we consider a setting with either zero or perfect spillovers.[9] The firms that enter into a coalition enjoy perfect spillovers, whereas the outsider can only improve on own costs through his own investments. The coalition partners operate as a form of Research Joint Venture (RJV) in which the partners share their technology advancements perfectly, but they choose both quantity and R&D spending non-cooperatively.[10]

To determine the sub-game perfect Nash equilibrium of the game we work backwards from stage 2, assuming that the firms act non-cooperatively at each stage. The maximization problem of firm i is

$$\max_{q_i} \ \pi_i = (1 - (q_i + q_j + q_k) - \theta_i c + x_i) q_i \tag{3}$$

Given the amount of R&D undertaken at stage 1, the quantity produced by each firm at stage 2 is:

$$\begin{aligned} q_i &= \frac{(1 - c\,(3\theta_i - \theta_j - \theta_k) + 3x_i - x_j - x_k)}{4} \\ q_j &= \frac{(1 - c\,(3\theta_j - \theta_i - \theta_k) + 3x_j - x_i - x_k)}{4} \\ q_k &= \frac{(1 - c\,(3\theta_k - \theta_j - \theta_i) + 3x_k - x_j - x_i)}{4} \end{aligned} \tag{4}$$

giving firm i a profit of $\pi_i = q_i^2$ in the product market. Firm i thus chooses its amount of R&D to solve the following problem:

$$\max_{x_i} \ \Pi_i = \pi_i - \frac{\gamma x_i^2}{2}. \tag{5}$$

The non-cooperative level of R&D by each firm in an interior equilibrium can then be determined to be

[9] The seminal paper on strategic R&D investments is d'Aspremont and Jacquemin (1988). Similar issues are analysed by Suzumura (1992), Leahy and Neary (1997), and Brod and Shivakumar (1997).

[10] In the terminology of Kamien, Muller and Zang (1992) we are analysing RJV with competition.

$$
\begin{aligned}
x_k &= \frac{3\,(2\gamma - 3 - 2\gamma c\,(3\theta_k - \theta_j - \theta_i) + 3\theta_k c)}{(8\gamma - 3)\,(2\gamma - 3)} \\
x_j &= \frac{3\,(2\gamma - 3 - 2\gamma c\,(3\theta_j - \theta_i - \theta_k) + 3\theta_j c)}{(8\gamma - 3)\,(2\gamma - 3)} \\
x_i &= \frac{3\,(2\gamma - 3 - 2\gamma c\,(3\theta_i - \theta_j - \theta_k) + 3\theta_i c)}{(8\gamma - 3)\,(2\gamma - 3)} \\
X &= x_i + x_j + x_k = \frac{3\,(3 - c(\theta_i + \theta_j + \theta_k))}{(8\gamma - 3)}
\end{aligned} \tag{6}
$$

where the second-order condition for each player's maximization and the stability condition is fulfilled for $\gamma > \frac{3}{2}$, making the sign of the denominator in (6) positive.[11] The first order conditions for the maximization of (5) yield the following relationship between quantity and R&D of firm $a = i, j, k$: $q_a = \frac{2\gamma}{3} x_a$.It is immediately apparent from (4) and (6) that $q_i > q_j > q_k$ and $x_i > x_j > x_k$ so that the most efficient firm at the outset (firm i) does the most R&D and produces the most output in the interior equilibrium. For the interior solution to be valid it must be the case that the R&D and output of the least productive firm must be positive ($q_k > 0$, $x_k > 0$) and the *ex post* cost of the most efficient firm likewise: $\theta_i c - x_i > 0$. This yields the following set of conditions:

$$
\begin{aligned}
\theta_i &> \frac{6c\gamma(\theta_j + \theta_k) + 3(2\gamma - 3)}{4c\gamma(4\gamma - 3)} \\
\theta_k &< \frac{(2\gamma - 3) + 2\gamma c(\theta_i + \theta_j)}{3c(2\gamma - 1)}
\end{aligned} \tag{7}
$$

Hence the interior equilibrium exists if firm i (k) is not too (in)efficient in relation to the rivals. Substituting (4) and (6) into (5) reveals the total profits for the three firms in this equilibrium as

$$
\begin{aligned}
\Pi_i &= \frac{\gamma\,(8\gamma - 9)}{18}\,(x_i)^2 \\
\Pi_j &= \frac{\gamma\,(8\gamma - 9)}{18}\,(x_j)^2 \\
\Pi_k &= \frac{\gamma\,(8\gamma - 9)}{18}\,(x_k)^2
\end{aligned} \tag{8}
$$

where $\Pi_i > \Pi_j > \Pi_k$ in equilibrium. The proportionality factor $\frac{\gamma(8\gamma-9)}{18}$ is strictly positive for all permissible values for γ.

The difference in the R&D of two firms that are adjacent in terms of cost, say i and j, is

$$
x_i - x_j = \frac{3c(\theta_j - \theta_i)}{2\gamma - 3} \tag{9}
$$

[11] On the stability condition in oligopoly models in general see Seade (1980). For their use in R&D models see Henriques (1990).

so that the difference in R&D is proportional to the difference in *ex ante* efficiency. The relationship for the *ex post* costs of these two firms is consequently:

$$\widehat{c}_j - \widehat{c}_i = (\theta_j c - x_j) - (\theta_i c - x_i) = \frac{2\gamma c(\theta_j - \theta_i)}{2\gamma - 3} \equiv \alpha c(\theta_j - \theta_i) \tag{10}$$

where the proportionality coefficient α is the same for the comparison between adjacent firms i and j, and j and k. Since $\alpha > 1$, there is a larger relative distance between the firms' marginal cost after R&D takes place.[12]

Later in the paper, we present a parameterized example in which $\theta_i = 1, \theta_j = 2, \theta_k = 3$. The existence conditions in (7) in this case amount to requiring:

$$\frac{2\gamma - 3)}{3(4\gamma - 3)} > c > \frac{3(2\gamma - 3)}{2\gamma\,(8\gamma - 21)}$$

The area in which the interior equilibrium is valid is drawn in Figure 1. Here, combinations of c and γ below the concave line secure that $x_k > 0$ whilst combinations above the convex one yield ex post positive costs for the most efficient firm: $c - x_i > 0$.

[Figure 1 about here]

3 Technology sharing between the most efficient firms

We now suppose that the two most efficient firms, i and j, agree to share the results of their independent R&D in the form of a technology sharing consortium. Each firm still decides how much to spend on R&D independently of the others, but i and j now get the full benefit of each others' advancement. The cost reducing R&D can be thought of as complementary R&D. There is, as before, no spillover to or from the outside firm k. Hence the *ex post* marginal production costs of the firms are given by

$$\begin{aligned} \widehat{c}_i^{ij} &= \theta_i c - x_i - x_j \\ \widehat{c}_j^{ij} &= \theta_j c - x_i - x_j \\ \widehat{c}_k^{ij} &= \theta_k c - x_k \end{aligned} \tag{11}$$

where $\widehat{c}_a^{ij}$ indicates the marginal cost post of R&D expenditures of firm $a = i, j, k$ given that i and j share technology advancements.

The profit levels of the firms before the R&D stage are given by

[12] The *ex ante* difference in costs is $c\,(\theta_j - \theta_i)$.

$$
\begin{aligned}
\Pi_i^{ij} &= \frac{\left(1-3\left(\theta_i c - x_i - x_j\right) + \theta_j c - x_i - x_j + \theta_k c - x_k\right)^2}{16} - \gamma \frac{x_i^2}{2} \\
\Pi_j^{ij} &= \frac{\left(1-3\left(\theta_j c - x_i - x_j\right) + \theta_i c - x_i - x_j + \theta_k c - x_k\right)^2}{16} - \gamma \frac{x_j^2}{2} \\
\Pi_k^{ij} &= \frac{\left(1-3\left(\theta_k c - x_k\right) + \theta_j c - x_i - x_j + \theta_i c - x_i - x_j\right)^2}{16} - \gamma \frac{x_k^2}{2}
\end{aligned}
$$

The interior R&D expenditures in equilibrium are then

$$
\begin{aligned}
x_i^{ij} &= \frac{\gamma\left(2\gamma-3\right) + 3c\left(\theta_j + \left(\gamma-1\right)\theta_i\right) + 7c\gamma\left(\theta_i - \theta_j\right) - 2c\gamma^2\left(3\theta_i - \theta_j - \theta_k\right)}{\gamma(8\gamma^2 - 17\gamma + 6)} \\
x_j^{ij} &= \frac{\gamma\left(2\gamma-3\right) + 3c\left(\theta_i + \left(\gamma-1\right)\theta_j\right) - 7c\gamma\left(\theta_i - \theta_j\right) - 2c\gamma^2\left(3\theta_j - \theta_i - \theta_k\right)}{\gamma(8\gamma^2 - 17\gamma + 6)} \\
x_k^{ij} &= \frac{3\gamma - 6\left(1 - \theta_k c\right) - 3c\gamma\left(3\theta_k - \theta_i - \theta_j\right)}{(8\gamma^2 - 17\gamma + 6)}
\end{aligned} \tag{12}
$$

where the denominator in these expressions is positive by the stability condition (requiring $\gamma > 1.678$). The R&D expenditure by the inside firms is decreasing in their own efficiency parameters ($\frac{\partial x_i^{ij}}{\partial \theta_i} = \frac{\partial x_j^{ij}}{\partial \theta_j} < 0$). The effect that the technology partner's efficiency has on own R&D depends upon the size of γ: for $3 > \gamma > 1.678$, $\frac{\partial x_j^{ij}}{\partial \theta_i} < 0$ and for $\gamma > 3$ we have that $\frac{\partial x_j^{ij}}{\partial \theta_i} > 0$ with the effect of j's efficiency on i's R&D defined symmetrically. To explain these effects is it useful to consider the R&D reaction functions of the firms:

$$
\begin{aligned}
x_i^{ij}(x_j^{ij}, x_k^{ij}) &= \frac{1 + c(-3\theta_i + \theta_j + \theta_k) + 2x_j^{ij} - x_k^{ij}}{4\gamma - 2} \\
x_j^{ij}(x_i^{ij}, x_k^{ij}) &= \frac{1 + c(-3\theta_j + \theta_i + \theta_k) + 2x_i^{ij} - x_k^{ij}}{4\gamma - 2} \\
x_k^{ij}(x_i^{ij}, x_j^{ij}) &= \frac{1 + c(-3\theta_k + \theta_j + \theta_i) - 2x_i^{ij} - 2x_j^{ij}}{4\gamma - 3}
\end{aligned} \tag{13}
$$

In the following we shall assume a fixed relationship between the initial efficiency levels of the three firms: $\theta_i = 1, \theta_j = 2, \theta_k = 3$.[13] Totally differentiating this system of equations and solving reveals that $\frac{dx_i^{ij}}{d\theta_i} < 0$ measured along i's reaction function; an increase in θ_i leads to a negative shift in the R&D reaction function of firm i inducing it to behave less aggressively. At the same time the reaction function of the outside firm k shifts positively. The total effect of an increase in θ_i on j's reaction function is parameter specific; when $\gamma > 2.68$ j's reaction function shifts positively as its partner becomes less efficient, whilst the opposite is the case for $2.68 > \gamma > 1.678$. Hence, when γ is large an increase in θ_i will reduce x_i^{ij} directly, but the positive shift in j's reaction function will counter some of this effect since the R&D expenditures of the partners are strategic complements. At the same time the positive shift in the outsider's R&D reaction function further reduces x_i^{ij}

[13] The same assumption of a fixed relationship between ex ante efficiency levels is used by Straume (2003).

since the R&D efforts of i and k are strategic substitutes. The overall effect of i's reduction in efficiency is a reduction in x_i^{ij}. When γ is small there is a negative shift in j's reaction function which further reduces i's R&D. The effects that an increase in θ_i has on the partner firm's R&D depend upon γ similarly. When γ is sufficiently large, the positive shift in j's reaction function outweighs the negative effect of i's R&D reduction. If γ is small then j's R&D reaction function moves negatively reinforcing the effect of i's reduced R&D.

R&D efforts of the coalition partners increase in the efficiency parameter of the outsider ($\frac{\partial x_i^{ij}}{\partial \theta_k} = \frac{\partial x_j^{ij}}{\partial \theta_k} > 0$); for the outsider it is the case that $\frac{\partial x_k^{ij}}{\partial \theta_k} < 0$. Here it is the case that the R&D expenditures of each coalition partner is a strategic substitute for that of the outsider. Total analysis of the system in (13) reveals that an increase in θ_k causes a negative shift in k's R&D reaction function, and a positive shift in that of the insiders. Hence the insiders' R&D increases whilst that of the outsider falls. Similarly, the outside firm devotes more resources to R&D when its rivals are less efficient initially ($\frac{\partial x_k^{ij}}{\partial \theta_i} = \frac{\partial x_k^{ij}}{\partial \theta_j} > 0$).

From (12) one can compute that $x_i^{ij} - x_j^{ij} = \frac{(\theta_j - \theta_i)}{\gamma} c > 0$ from which it is apparent that $x_i^{ij} > x_j^{ij}$ for all permissible values of γ. Hence the firm that is most efficient initially will undertake more R&D than the less efficient partner, but since all technology advancements are shared among the coalition partners the gap in the R&D levels of the two inside firms is smaller than in the no-coalition case (see (9)). Other relative comparisons rest on the specific relationship between the three efficiency parameters so we now focus on the parametric example: $\theta_i = 1, \theta_j = 2, \theta_k = 3$. This yields the following R&D levels in equilibrium:

$$\begin{aligned} x_i^{ij} &= \frac{\left(3c - 3\gamma - 4c\gamma + 2\gamma^2 + 4c\gamma^2\right)}{\gamma(8\gamma^2 - 17\gamma + 6)} \\ x_j^{ij} &= \frac{\left(13c\gamma - 3\gamma - 3c + 2\gamma^2 - 4c\gamma^2\right)}{\gamma(8\gamma^2 - 17\gamma + 6)} \\ x_k^{ij} &= \frac{3\,(\gamma - 6c\gamma + 6c - 2)}{(8\gamma^2 - 17\gamma + 6)} \end{aligned} \tag{14}$$

In all of the coalition cases that we consider, there is a simple relationship between quantities, total profits, and R&D expenditure in equilibrium. Suppose that two firms (call them m and n) cooperate on R&D whilst firm p is outside. Then equilibrium quantities and total profit in equilibrium are easily determined to be:

$$\begin{aligned} q_m^{mn} &= \gamma x_m^{mn} \\ q_n^{mn} &= \gamma x_n^{mn} \\ q_p^{mn} &= \frac{2\gamma}{3} x_p^{mn} \end{aligned} \tag{15}$$

$$
\begin{aligned}
\Pi_m^{mn} &= \frac{\gamma(2\gamma-1)}{2}\left(x_m^{mn}\right)^2 \\
\Pi_n^{mn} &= \frac{\gamma(2\gamma-1)}{2}\left(x_n^{mn}\right)^2 \\
\Pi_p^{mn} &= \frac{\gamma(8\gamma-9)}{18}\left(x_p^{mn}\right)^2
\end{aligned}
\tag{16}
$$

For this equilibrium to be valid when i and j are the insiders, the R&D efforts, quantities, *ex post* marginal costs, and profits of all three firms must be non-negative. Figure 2 delineates the parameter values that are consistent with this equilibrium as areas I, II and III; the equations of lines A, B, C and D are given in the appendix.

[Figure 2 about here]

Parameter combinations above and to the right of line A ensure that the *ex post* marginal cost of the most efficient firm i is positive (and hence that of the partner j will also be positive); the condition ensuring that the *ex post* cost of k is positive does not bind and is not drawn in the figure. Combinations below line B yield $x_k^{ij} > 0$, and here the other firms' R&D levels are also positive. It is also easy to check that the same conditions that ensure positive R&D expenditures also secure positive quantities in the product market. Between B and C in area I we find that $x_i^{ij} > x_j^{ij} > x_k^{ij} > 0$. The intersection of A and B defines $\gamma = 5$ as the lowest value of this parameter that is consistent with the equilibrium. In area II we have that $x_i^{ij} > x_k^{ij} > x_j^{ij} > 0$ whilst in III it is the least effective firm (the outsider) that has the most R&D: $x_k^{ij} > x_i^{ij} > x_j^{ij} > 0$. Hence we have $x_k^{ij} = x_j^{ij}$ along C and $x_k^{ij} = x_i^{ij}$ along line D. It can easily be verified that profit is positive in areas I, II and III.

To explain the relative sizes of the R&D efforts, it is again instructive to consider the gross changes in the R&D reaction functions in (13) that are caused by changes in the parameters c and γ. It can be determined that the R&D reaction functions of j and k shift negatively when c increases, with that of k showing the most negative change. The R&D reaction function of i shifts positively. Consider a point on line C in Figure 2 that is consistent with equilibrium; here $x_j^{ij} = x_k^{ij}$. Now increase c, keeping γ fixed so that we move into area I. This shifts the reaction functions of j and k negatively, but the latter moves most. Hence x_j^{ij} increases above x_k^{ij}. Correspondingly, reducing c from a point on C, into area II, increases x_k^{ij} most. A parallel argument can be made for the comparison between x_i^{ij} and x_k^{ij} in areas II and III.

Since firms i and j share the results of their R&D, the relative difference in their efficiency levels is also preserved *ex post*. The difference in *ex post* marginal cost for the coalition partners is simply the *ex ante* difference c, and since $x_i > x_j$, where x_i is defined by (6), it can be shown that the difference in *ex post* marginal costs between the coalition partners is lower than the benchmark case of no coalition. The partner firms manage to gain an additional advantage over the outsider if the sum of their R&D is larger than that of the outsider; i.e., if $x_m^{mn} + x_n^{mn} > x_p^{mn}$ when firms

m and n are in a coalition and firm p is the outsider. This is the case in the equilibrium discussed here. Hence, the technology sharing arrangement between the two most efficient firms serves to further disadvantage the less efficient rival.

The intuition behind the results can be explained as follows: The R&D effort of the two coalition partners are strategic complements due to perfect spillovers, which lead to lower levels of investments for both the partners compared to the no-coalition case. Furthermore, since spillovers are perfect and the R&D costs are convex, the most efficient firm which invests the most in the no-coalition case will face a stronger free-riding effect than the coalition partner and will reduce its investment level more than its partner. This explains why the difference in investment levels between firms i and j in the no-coalition is higher than in the coalition case. For the partners, the R&D effort of the outsider is perceived as a strategic substitute to the partners' effort, and since the coalition partners reduce their overall investment level this implies that the outsider invests more relative to the coalition partners than in the benchmark case. The outsider, in this case firm k, still invests less than in the no-coalition case, but the difference in investment level relative to the second-most efficient firm is lower in the coalition case, with $\left(x_j^{ij} - x_k^{ij}\right) - (x_j - x_k)$ being negative.

4 Technology sharing between the most and least efficient firms

Suppose now that firms i and k join together in the technology sharing arrangement whilst j is outside the arrangement. In the parameterized example, marginal costs after R&D are now given by

$$\begin{aligned} \widehat{c}_i^{ik} &= c - x_i^{ik} - x_k^{ik} \\ \widehat{c}_k^{ik} &= 3c - x_i^{ik} - x_k^{ik} \\ \widehat{c}_j^{ik} &= 2c - x_j^{ik} \end{aligned} \tag{17}$$

Equilibrium R&D are

$$\begin{aligned} x_i^{ik} &= \frac{\left(6c - 3\gamma - 11c\gamma + 2\gamma^2 + 4c\gamma^2\right)}{\gamma(8\gamma^2 - 17\gamma + 6)} \\ x_j^{ik} &= \frac{3\,(2c-1)\,(2-\gamma)}{(8\gamma^2 - 17\gamma + 6)} \\ x_k^{ik} &= \frac{\left(-6c - 3\gamma + 23c\gamma + 2\gamma^2 - 12c\gamma^2\right)}{\gamma(8\gamma^2 - 17\gamma + 6)} \end{aligned} \tag{18}$$

and the quantities and profits follow (15) and (16).

The conditions that guarantee the existence of this equilibrium are presented in Figure 3 as parameter combinations in areas IV and V.[14] In V it is the case that the outsider has most R&D ($x_j^{ik} > x_i^{ik} > x_k^{ik}$) whilst in IV the relative comparison is $x_i^{ik} > x_j^{ik} > x_k^{ik}$. In both cases, the relative ranking of the three firms in terms of *ex post* marginal cost is the same as at the outset: $\widehat{c}_k^{ik} > \widehat{c}_j^{ik} > \widehat{c}_i^{ik}$. The technology sharing arrangement does, however, allow the least efficient firm to close the gap on the outsider since $\widehat{c}_k^{ik} - \widehat{c}_j^{ik} < c$ where c is the initial gap in efficiency. The most efficient firm also increases its cost advantage over the outsider. Both of these results follow since $x_i^{ik} + x_k^{ik} > x_j^{ik}$.

The intuition behind these results are essentially the same as described above. The outsider, firm j, has stronger incentives to invest in cost reducing R&D than the insiders. This is due to the fact that the insiders face free-riding issues and strategic complementarity between their investments, which reduces their investments and reduces the investment of the *ex ante* most efficient firm most. Since the insiders' investment and that of the outsider are strategic substitutes, the reduction in the coalition partners' investments results in higher investment by the outsider. The reason why the outsider may, for some parameter values, invest more than the most efficient insider is that for some levels of the initial marginal cost, c, the percentage reduction in ex post marginal cost due to R&D is sufficiently large.

5 Coalition between the two least efficient firms

The final possibility that we consider is one in which the least efficient firms, j and k, agree to share the results of their R&D, with the most efficient firm outside of the arrangement. *Ex post* costs are then

$$\begin{aligned} \widehat{c}_i^{jk} &= c - x_i^{jk} \\ \widehat{c}_k^{jk} &= 3c - x_j^{jk} - x_k^{jk} \\ \widehat{c}_j^{jk} &= 2c - x_j^{jk} - x_k^{jk} \end{aligned} \tag{19}$$

with equilibrium R&D:

$$\begin{aligned} x_i^{jk} &= \frac{3\left(2c+\gamma+2c\gamma-2\right)}{8\gamma^2-17\gamma+6} \\ x_j^{jk} &= \frac{\left(3c-3\gamma-c\gamma+2\gamma^2-4c\gamma^2\right)}{\gamma\left(8\gamma^2-17\gamma+6\right)} \\ x_k^{jk} &= \frac{\left(16c\gamma-3\gamma-3c+2\gamma^2-12c\gamma^2\right)}{\gamma\left(8\gamma^2-17\gamma+6\right)} \end{aligned} \tag{20}$$

[14] Along E in this figure we have $x_k^{ik} = 0$, G denotes $\widehat{c}_i^{ik} = 0$, and F gives $x_i^{ik} = x_j^{ik}$. The equations for these loci are given in the appendix.

Again, equilibrium quantities and profits follow the pattern in (15) and (16).

Again, considering the constraints that allow this equilibrium leads to Figure 4, and parameter combinations in areas VI and VII which represent the constraints $x_k^{jk} > 0$ (below locus J in Figure 4) and $\widehat{c}_i^{jk} > 0$ (above H) that bind in this case. For these values one can determine that $x_i^{jk} > x_j^{jk} > x_k^{jk} > 0$. In VI we have that, $x_i^{jk} > x_j^{jk} + x_k^{jk}$ so that the coalition partners lose ground to the most efficient firm in terms of *ex post* cost in spite of the fact that they share their new knowledge. Hence $\widehat{c}_k^{jk} > \widehat{c}_j^{jk} > \widehat{c}_i^{jk}$ in this area.[15] In VII we find that $x_i^{jk} < x_j^{jk} + x_k^{jk}$ so that the coalition partners gain relative to the outsider, but they do not catch up completely: $\widehat{c}_k^{jk} > \widehat{c}_j^{jk} > \widehat{c}_i^{jk}$ here also.

6 Comparison of R&D levels

In this section we look at the relative properties of the four cases considered. The four figures make it clear that the cases hold for different sets of parameter values, and that any comparison between the cases must take this into account. Comparing the expression that underlie Figures 1-4 reveals that the area of existence for the case in which the most efficient firms cooperate is encompassed by that of all other cases, and hence the equilibria exist collectively for

$$\frac{\gamma - 2}{6(\gamma - 1)} > c > \frac{2(2\gamma - 3)}{8\gamma^2 - 17\gamma - 3}$$

One can determine that the relationship between the total amounts of R&D undertaken is given by $X > X^{jk} > X^{ik} > X^{ij}$. For the most efficient firm we find that $x_i > x_i^{jk} > x_i^{ij} > x_i^{ik}$ so that it undertakes the most R&D in the stand-alone situation. Of the cooperative solutions it conducts most R&D as an outsider to a technology sharing partnership. For the intermediate firm the comparison is also straightforward: $x_j > x_j^{ik} > x_j^{ij} > x_j^{jk}$. For the least efficient firm the comparison is partly parameter specific. It is, however, unambiguously the case that $x_k > x_k^{ij}$ and $x_k^{ik} > x_k^{jk}$. Furthermore when c is sufficiently large[16] then $x_k^{ij} > x_k^{ik}$.

The level of the *ex ante* cost difference, c, plays an important role in the analysis. The comparative static results for R&D expenditures show that the equilibrium level of investment is affected by an increase in c in the following way:

$$\begin{aligned} \frac{\partial x_i^h}{\partial c} &> 0 \\ \frac{\partial x_j^h}{\partial c} &< 0 \\ \frac{\partial x_k^h}{\partial c} &< 0 \end{aligned} \tag{21}$$

[15] This is the case for for $c > \frac{\gamma}{22\gamma - 9}$.

[16] Specifically $c > \frac{\gamma(\gamma-3)}{6\gamma^2+5\gamma-6}$.

for all h, where h denotes the type of coalition; $h = \{ij, ik, jk\}$. Thus, the most efficient firm will in all of the coalition cases increase expenditure on R&D when the ex ante cost difference increases.[17] This is also the case when firms operate without technology sharing arrangements. Since both quantity and profits are proportional to R&D expenditure, the comparative statics with respect to changes in c will have the same signs as (21). The reason for this seemingly unintuitive comparative statics results is due to the fact that when c increases firms become more asymmetric *ex ante*, and our specification of the asymmetry between firms implies that for each unit of increase in c the marginal cost of firm j increases two-fold and firm firm k the increase is three-fold. This implies that *ex ante* most efficient firm enjoys a substantially larger percentage reduction in *ex post* marginal cost from any given R&D investment, and hence the results in (21).

7 Equilibrium technology sharing arrangement

In order to establish which, if any, technology sharing arrangement would arise endogenously, we need to compare industry profit for the different coalitions. The arrangement that yields the highest level of industry profit will be the chosen coalition, provided that this structure awards the coalition partners higher profit than the default outcome; i.e., the sum of profit for the coalition partners in the absence of a technology sharing arrangement. This ensures that the coalition cannot be broken by an offer from an outsider, and that the partners would enter the coalition voluntarily given the status quo represented by the initial situation.[18] Let us define $\Delta_1 \equiv \Pi^{ij} - \Pi^{ik}$ and $\Delta_2 \equiv \Pi^{ij} - \Pi^{jk}$, where $\Pi^{st} \equiv \Pi_i^{st} + \Pi_j^{st} + \Pi_k^{st}$ is the industry profit with a coalition between firms s and t, for $s, t = i, j, k$ with $i \neq j \neq k$. It can be shown that the following holds:

$$\Delta_1 = \frac{c(2\gamma - 1)\left(c\gamma^2(200\gamma - 429) + c(306\gamma - 54) + \gamma^2(40\gamma - 54)\right)}{2\gamma(8\gamma^2 - 17\gamma + 6)^2} > 0 \tag{22}$$

$$\Delta_2 = -\frac{2c\gamma(2c - 1)(20\gamma - 27)(2\gamma - 1)}{(8\gamma^2 - 17\gamma + 6)^2} > 0 \tag{23}$$

This implies that the industry profit is highest when firms i and j, i.e., the two most efficient firms, enter into a technology sharing consortium. In order to obtain a complete ranking of all the three coalition outcomes, let us define $\Delta_3 \equiv \Pi^{jk} - \Pi^{ik}$ which can be written as:

$$\Delta_3 = \frac{c(2\gamma - 1)\left(c(306\gamma - 54) - \gamma^2(40\gamma - 54) + c\gamma^2(360\gamma - 645)\right)}{2\gamma(8\gamma^2 - 17\gamma + 6)^2} \tag{24}$$

The sign on eqn.(24) is ambiguous, but $\Delta_3 \geq 0$ if:

$$c \geq \bar{c} \equiv \frac{\gamma^2(40\gamma - 54)}{(306\gamma(1 + \gamma^2) - 645\gamma^2 - 54)} \tag{25}$$

[17] Recall that an increase in c causes i's R&D reaction function to shift positively, whilst those of the other firms react negatively in our example.

[18] See Horn and Persson (2001) or Straume (2003).

If (25) holds, the ranking between industry profits for the three coalitions is:

$$\Pi^{ij} > \Pi^{jk} \geq \Pi^{ik} \geq 0 \tag{26}$$

If (25) is violated, the ranking of industry profit is:

$$\Pi^{ij} > \Pi^{ik} \geq \Pi^{jk} \geq 0 \tag{27}$$

To ensure that the coalition between firms i and j is the equilibrium technology sharing agreement, we need to ensure that firms i and j cannot earn higher profits without a coalition. Define $\Delta_4 \equiv \Pi_i^{ij} + \Pi_j^{ij} - \Pi_i - \Pi_j$. We can show the following:

$$\Delta_4 = \frac{\gamma\left(2\gamma-1\right)}{2}\left(\left(x_i^{ij}\right)^2 + \left(x_j^{ij}\right)^2\right) - \frac{\gamma\left(8\gamma-9\right)}{18}\left(\left(x_i\right)^2 + \left(x_j\right)^2\right) \tag{28}$$

We have already seen that the non-cooperative R&D levels are strictly higher for firms i and j, but the factor $\frac{\gamma(2\gamma-1)}{2}$ is larger than $\frac{\gamma(8\gamma-9)}{18}$. To check that $\Delta_4 > 0$ first note that as $\gamma \to \infty, \Delta_4 \to 0$. The area in which the equilibria that underlie Δ_4 exist is given by $\frac{\gamma-2}{6(\gamma-1)} > c > \frac{2(2\gamma-3)}{8\gamma^2-17\gamma-3}$ which is the area between A and B in Figure 2. Evaluating Δ_4 at a point on either of these lines reveals that $\Delta_4 > 0$. Furthermore, from this point we have that $\frac{\partial \Delta_4}{\partial \gamma} < 0$ so that $\Delta_4 \to 0$ from above as γ increases. Hence for parameter combinations of c and γ in the permissible range we have $\Delta_4 > 0$. Hence, we have shown the main result of the paper that a coalition consisting of the two most efficient firms will be the equilibrium coalition structure.

8 Welfare comparison and discussion

The outcome of a process of endogenous coalition formation is shown to be technology sharing between the two most efficient firms. We now consider the effects that this will have on the product market equilibrium and consumer surplus in this market.

We have shown above that of the three coalition outcomes the industry profit is highest when the two most efficient firms enter into a technology sharing consortium, with Π^{ij} being strictly larger than Π^{ik} and Π^{jk} (see (26) and (27)). It can also be shown that the industry profit without coalitions is strictly lower than the equilibrium coalition, since $\Pi^{ij} > \Pi$ where $\Pi = \Pi_i + \Pi_j + \Pi_k$ represents the non-cooperative case. Furthermore, it can be shown that $\Pi^{jk} > \Pi$, but Π^{ik} may be either higher or lower than Π. However, if (25) is violated with $c < \overline{c}$, then we know that $\Pi^{ij} > \Pi^{ik} > \Pi^{jk} > \Pi$ with industry profit in the equilibrium coalition being the highest of the potential outcomes considered.

It is also easily shown that consumers' surplus, given by $CS^{mn} = \left(Q^{mn}\right)^2/2$, has the following ranking (for all c and γ):

$$CS^{ij} > CS^{ik} > CS^{jk} > CS$$

Consequently, when $c < \overline{c}$ the ranking of welfare is given by (this is the area between lines K and A in figure 5):

$$W^{ij} > W^{ik} > W^{jk} > W$$

where $W^{mn} \equiv CS^{mn} + \Pi^{mn}$. When $c > \overline{c}$, we know that welfare is highest when the two most efficient firms are allowed to share technology advancements, since $W^{ij} > W$, and we know that $W^{jk} > W$. A complete welfare ranking in this case will be parameter specific.

In the context of the present model, we observe that there are no conflicting interests between consumers and firms in terms of which coalition outcome is preferred provided that the *ex ante* difference between firms, c, satisfies $c < \overline{c}$. This is, perhaps, surprising since one hypothesis might be that higher levels of R&D lead to higher consumers' surplus and welfare, and we know that the total level of R&D is in fact lowest with a coalition between firms i and j. The ranking is a consequence of total output being $Q^{ij} > Q^{ik} > Q^{jk} > Q$ which is inversely related to total R&D. The difference between total output in the three potential coalition outcomes is proportional to the parameters c and γ, with $Q^{ij} - Q^{ik} = \gamma c$ and $Q^{ik} - Q^{jk} = \gamma c$. We need to look at other factors to explain why consumers (together with firms and welfare maximizing authorities) prefer the outcome with the lowest level of R&D expenditure.

As is well known from Bergstrom and Varian (1985), the Nash outcome of a class of games will be independent of the distribution of the firms' characteristics. In terms of the present game, the total output in the final stage is independent of the individual firm's *ex post* marginal cost and depends only on the sum of the firms' *ex post* marginal costs, since $Q = (3 - (\widehat{c}_i + \widehat{c}_j + \widehat{c}_k))/4$. This implies that it is not the total R&D effort that matters, but the effective reduction in the sum of marginal costs that results from the R&D activities. Since there are perfect spillovers within a coalition which adds to the benefit of R&D, the effective reduction in marginal costs will depend on whether there is a coalition and which firms enter into a technology sharing coalition. The effective reduction in the case of no coalition is simply given by total R&D, X, and $2(x_m^{mn} + x_n^{mn}) + x_p^{mn}$ in the case of a coalition between firms m and n, where firm p is the outsider. It can easily be shown that the effective reduction in the sum of marginal costs is highest when firms i and j enter into a coalition, and that the rest of the potential outcomes confirms the consumers' surplus ranking. Consequently, even if the total level of R&D is lower in all of the three potential coalitions the fact that each unit of R&D undertaken by the coalition partners effectively counts twice.

In the analysis we have assumed that only two firms can enter into a coalition, but it may also be of interest to see if allowing all three firms to enter into a coalition may have an effect on the outcome. We still maintain the assumption that firms only share the technology advancements from stage 1 of the game, and that they undertake their investment choices non-cooperatively and there is no cooperation in the product market. In this case, the R&D investment undertaken by the firms benefit all coalition partners equally due to the assumption of perfect spillover, and the investments will naturally not yield a competitive advantage. The perfect spillovers also imply that the free-rider problem is pronounced, and it can be shown that the total level of R&D investments in the monopoly coalition is only one third of the total R&D investments without coalition. When all three firms agree to share their technology advancements this implies that the effective reduction in the sum of marginal costs, and thereby the total output, will be identical to the no-coalition case. Consequently, consumers will be indifferent between a coalition involving all three firms and no coalition. It can also be shown that the equilibrium coalition of the two most efficient firms will dominate the coalition of all three firms.

9 Concluding remarks

In this paper we have addressed the issue of cooperation in R&D strategy between heterogeneous firms by allowing endogenous coalition formation. When the two most efficient firms join together and share technological breakthroughs, it is not possible for the outsider to offer either of the partners a better deal. In addition the partners prefer sharing their technology over the initial non-cooperative situation. Hence this is the technology sharing agreement that will arise endogenously. Moreover, we have shown that this agreement also maximizes the total welfare in society.

In terms of the welfare ranking of the outcomes, we have seen that the virtue of perfect spillover is to add additional benefit to a coalition by in essence double the impact of any R&D undertaken by firms in a coalition. If the coalition partners enjoy less than perfect spillovers, then the results with respect to the welfare ranking could be changed. This is, in particular, the case with spillovers close to zero. In such a case, the value for society in terms of added consumers' surplus of allowing a coalition is low. Nevertheless, if the coalition is costless for a participating firm it may still choose to agree to such a coalition even with very low spillovers, provided that the cost advantage of the firm over its rivals is not deteriorated. Furthermore, we have assumed a fixed *ex ante* cost difference between firms which facilitates the analysis, but implies some loss of generality.

10 References

Allen, R., 1983. Collective invention. Journal of Economic Behavior and Organization 4, 1-24

Barros, P., 1998. Endogenous mergers and size asymmetry of merger participants. Economics Letters 60, 113-119

Bergstrom, T., Varian, H., 1985. When are Nash equilibria independent of the distribution of agents' characteristics?. Review of Economic Studies 52, 715-718

Brod, A., Shivakumar, R., 1997. R&D cooperation and the joint exploitation of R&D. Canadian Journal of Economics 30, 673-684

Buchanan, J., 1965. An economic theory of clubs. Economica 32(125), 1-14

Carter, A., 1989. Knowhow trading as economic exchange. Research Policy 18, 155-163

Chatterjee, K., Dutta, B., Ray, D., Sengupta, K., 1993. A theory of noncooperative coalitional bargaining. Review of Economic Studies 60, 463-477

d'Aspremont, C., Jacquemin, A., 1988. Cooperative and noncooperative R&D in duopoly with spillovers. American Economic Review 78, 1133-1137

Eaton, B.C., Eswaran, M., 1997. Technology-trading coalitions in supergames. Rand Journal of Economics 28 (1), 135-149

Fried, D., 1984. Incentives for information production and disclosure in a duopolistic environment. Quarterly Journal of Economics 99, 367-381

Gal-Or, E., 1985. Information sharing in oligopoly. Econometrica 53, 329-343

Gal-Or, E., 1986. Information transmission - Bertrand and Cournot equilibria. Review of Economic Studies 53, 85-92

Henriques, I., 1990. Cooperative and noncooperative R&D in Duopoly with spillovers: Comment. American Economic Review 80, 638-640

Horn, H., Persson, L., 2001. Endogenous mergers in concentrated markets. International Journal of Industrial Organization 19, 1213-1244

Kamien, M., Muller, E., Zang, I., 1992. Research joint ventures and R&D cartels. American Economic Review 82, 1293-1306

Kamien, M., Zang, I., 1990. The limits to monopolization through acquisition. Quarterly Journal of Economics 2, 465-499

Kamien, M., Zang, I., 1991. Competitively cost advantageous mergers and monopolization. Games of Economic Behaviour 3, 323-338

Leahy, D., Neary, J.P., 1997. Public policy towards R&D in oligopolistic industries. American Economic Review 87, 642-662

Lerner, J., Tirole, J., 2004. Efficient patent pools. American Economic Review 94(4), 691-711

Lerner, J., Tirole, J., 2005. The economics of technology sharing: Open source and beyond. Journal of Economic Perspectives 19 (2), 99-120

Okuno-Fujiwara, M., Postlewaite, A., Suzumura, K., 1990. Strategic information revelation. Review of Economic Studies 57, 25-47

Ray, D., Vohra, R., 1999. A theory of endogenous coalition structure. Games of Economic Behaviour 26, 286-336

Seade, J., 1980. The stability of Cournot revisited. Journal of Economic Theory *48*, 479-489

Shapiro, C., 1986. Exchange of cost information in oligopoly. Review of Economic Studies 53, 433-446

Straume, O.R., 2003. Managerial delegation and merger incentives. Working Papers in Economics No. 04/03, Department of Economics, University of Bergen

Suzumura, K., 1992. Cooperative and noncooperative R&D in an Oligopoly with spillovers. American Economic Review 82, 1307-1320

Vasconcelos, H., 2006. Endogenous mergers in endogenous sunk cost industries. International Journal of Industrial Organization 24, 227-250

Vives, X., 1986. Duopoly information equilibrium: Cournot and Bertrand. Journal of Economic Theory 34, 71-94

von Hippel, E., 1987. Cooperation between rivals: Informal knowhow trading. Research Policy 16, 291-302

11 Figures

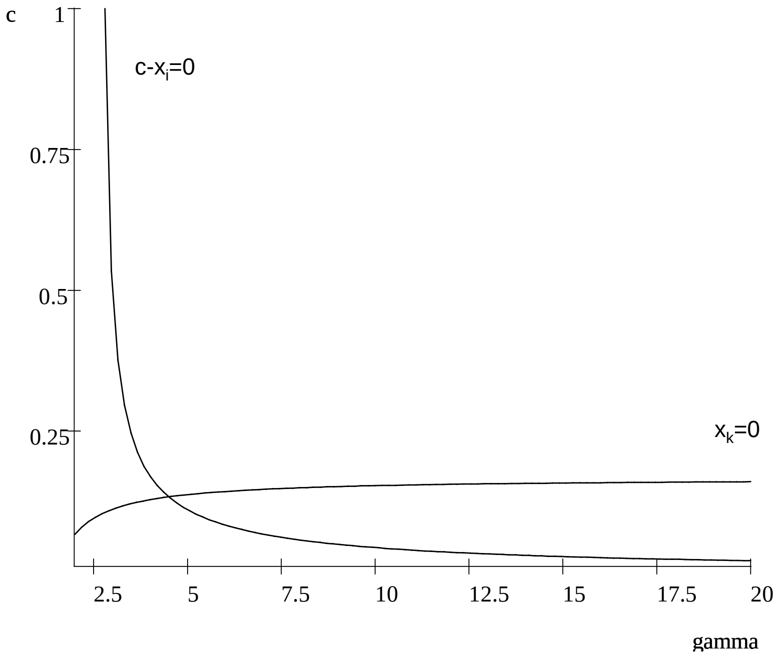

Figure 1: Non-cooperative case

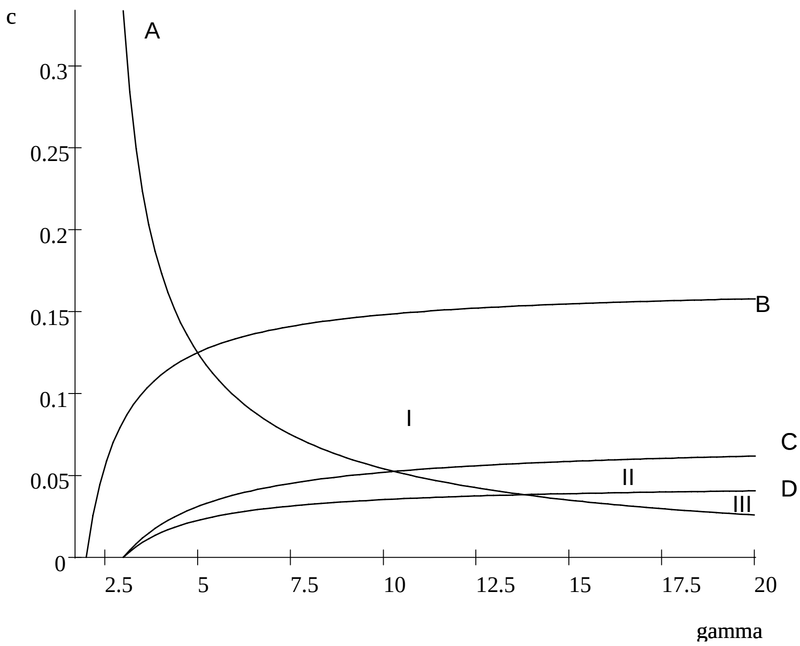

Figure 2: Coalition between the two most efficient firms

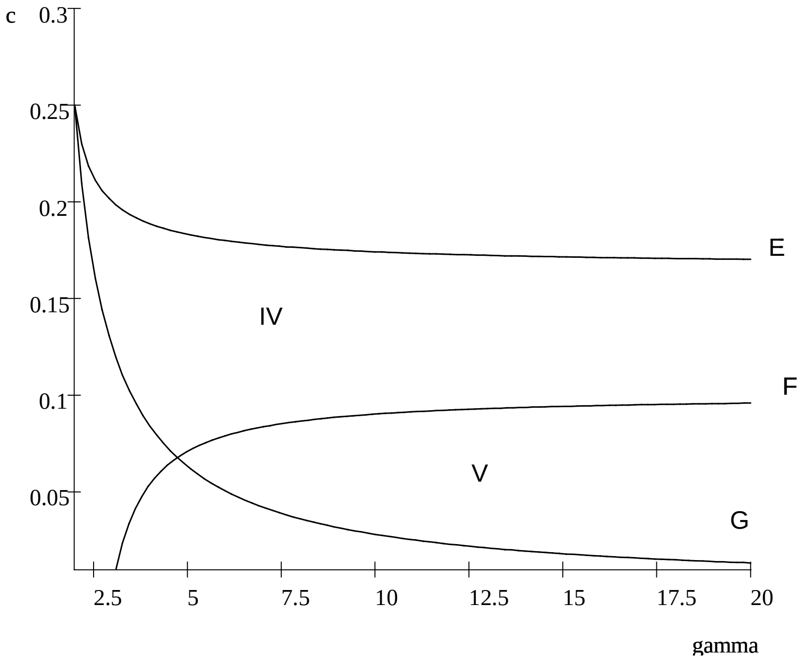

Figure 3: Coalition between the most and least efficient firms

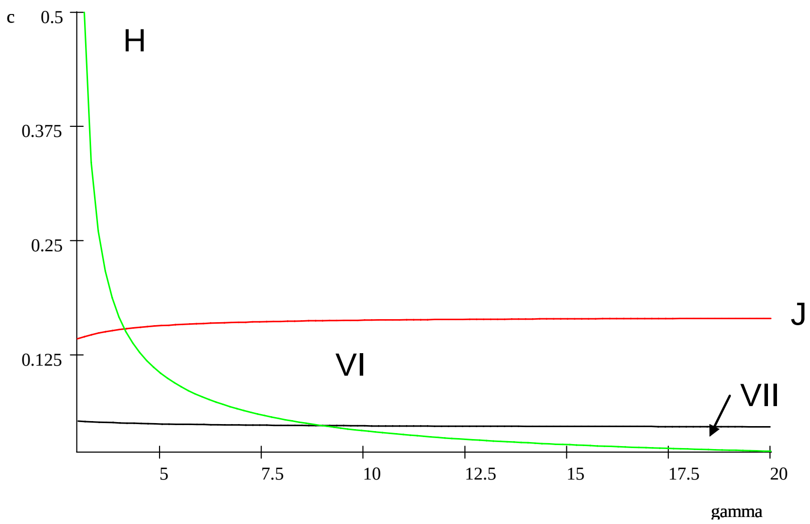

Figure 4: Coalition between the two least efficient firms

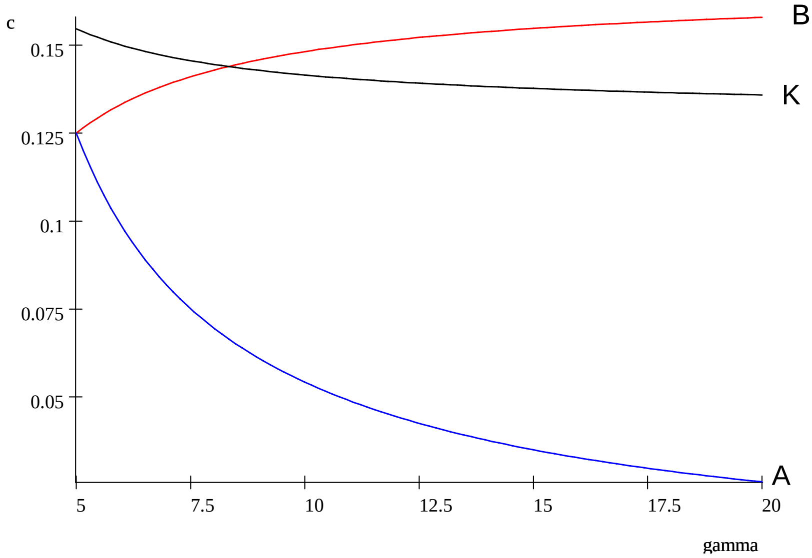

Figure 5: Welfare comparison

12 Appendix

The equations of lines A, B, C and D in Figure 2 are:

$$
\begin{aligned}
A &: \quad c = \frac{4\gamma - 6}{8\gamma^2 - 17\gamma - 3} \\
B &: \quad c = \frac{2 - \gamma}{6\,(1 - \gamma)} \\
C &: \quad c = \frac{\gamma\,(\gamma - 3)}{14\gamma^2 - 5\gamma - 3} \\
D &: \quad c = \frac{\gamma\,(\gamma - 3)}{22\gamma^2 - 22\gamma + 3}
\end{aligned}
$$

The equations of lines E, F and G in Figure 3 are:

$$
\begin{aligned}
E &: \quad c = \frac{\gamma(2\gamma - 3)}{12\gamma^2 - 23\gamma + 6} \\
F &: \quad c = \frac{\gamma(\gamma - 3)}{(3 - 10\gamma)(2 - \gamma)} \\
G &: \quad c = \frac{4\gamma - 6}{8\gamma^2 - 9\gamma - 6}
\end{aligned}
$$

The equations of lines H and J in Figure 4 are:

$$
\begin{aligned}
H &: \quad c = \frac{\gamma(3 - 2\gamma)}{16\gamma - 12\gamma^2 - 3} \\
J &: \quad c = \frac{3\gamma - 6}{8\gamma^2 - 23\gamma}
\end{aligned}
$$

The equation of line K in Figure 5 is (the equations of lines A and B are given above):

$$
K: \; c = \frac{\gamma^2\,(40\gamma - 54)}{(306\gamma\,(1 + \gamma^2) - 645\gamma^2 - 54)}
$$